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A NEW BASELINE FOR THE INERTIAL NAVIGATION STRAPDOWN SIMULATOR PROGRAM

VOLUME I Introduction and Summary

by

R.J. Russo, J.T. Prohaska, D.G. Riegsecker

July 1978

The Charles Stark Draper Laboratory, Inc.
Cambridge, Massachusetts 02139

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This four-volume report describes an updated and expanded version of a direct, digital, modular simulation of a strapdown inertial navigation system employing a wander-azimuth computational frame, and subject to a six degree of freedom random vibration environment. The original version of this simulation was developed under Task 4.2.3(a) of the above contract during 1975 and 1976.

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The user may simulate not only the gross dynamics of the flight profile (from an external or internal profile generation) but also the angular and linear random vibrations resulting from gusts and turbulence acting on the airframe. The total environment is applied to the models of the inertial components (laser or SDR gyros and pendulous accelerometers). The resulting outputs of simulated IMU are summed in an interface module and compensated and scaled in the simulated navigation computer. The latter also contains the velocity/attitude algorithm, which computes the body-to-inertial transformation, using either the direction cosine matrix or quaternion, and the navigation algorithm which numerically integrates the specific forces after transformation to the local vertical, wander azimuth computational frame. The outputs of the simulated navigation computer are the computed position, velocity, and attitude of the vehicle with respect to a local vertical, north pointing frame. The flight profile and the differences between it and the simulated navigation computer outputs are tabulated in an evaluation module for printing, plotting, or post processing.

A ground alignment Kalman filter for the INSS, also developed under this task, is not documented in this report, but may be available from AFAL/RWA-2 or -3.

The program is written in Fortran IV for use on a CD6600/CYBER74.

The report is structured as follows:

- Volume I is the Introduction and Summary
- Volume II contains analytical development of the equations to be mechanized and the transition to difference equation form
- Volume III is the Program Description and User's Guide
- Volume IV contains Program Listings.

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The Draper Laboratory program manager for this task is John Harper and the lead engineer is Roy Nurse. The authors of the report are Roy Nurse, John Prohaska, and Darold Riegsecker.

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INTRODUCTION

1.1 Purpose

This final report is intended as the complete documentation of a direct, digital simulation of a strapdown inertial navigation system, (INS). The simulation was originally developed for AFAL as Task 4.2.3(a) under Contract F33615-75-C-1149. The present version of the simulation- the new baseline- represents modifications, expansions and corrections of the original program. This latter work was undertaken as part of Task 4.5 of the above contract.

1.2 Background

Original program development was motivated by the need for a flexible, powerful tool for evaluating the effects of a highly dynamic, tactical aircraft environment on the performance of the inertial components in a strapdown aircraft inertial measurement unit and hence, on the resulting INS navigation and attitude performance. As a part of such a tool, fairly detailed models of the inertial components and their associated electronics were required, and were included in the original program. Component compensation almost as complex as the component models was also provided in the program. To follow this, the normal velocity-attitude and navigation algorithms were incorporated to provide computed position and velocity, with vertical channel stabilization from a simulated barometric altimeter.

All the foregoing were to be driven by the AFAL-supplied aircraft profile generator, PROFGEN(2), and an internal environment routine, which directly simulated random linear and angular vibrations, which were added to the PROFGEN outputs to drive the simulated INS. PROFGEN itself supplied the reference position and velocity. These were differenced with the simulated INS navigation outputs and the "errors" were printed out.

A program embodying the above characteristics was delivered to AFAL in the early spring of 1976, followed by a draft report, described as a module description and user's guide. In late 1976 and early 1977, the draft was expanded to contain some further tutorial matter. This was issued as R-969, dated February 1977.

1.3 Current Efforts

Further expansion of the documentation and of the program was deemed necessary, so the current work, which is documented herein, commenced in June 1977.

The initial objectives of these recent efforts were to provide:

1. the analytical development of the equations mechanized in the program.
2. the transition between the analytical form and the program code.
3. added features such as attitude and attitude errors, alternate direction cosine matrix updating of the body-to-inertial transformation.
4. new laser gyro and compensation modules.
5. corrections of any gross errors noted in the foregoing steps.

An additional objective was added near the conclusion of the current efforts: namely, the upgrading of the simulated navigation software -- the velocity-attitude and navigation algorithms -- to the best available from (5).

This report is contained in four volumes and an addendum:

Volume I contains the summary and conclusions.
Volume II contains an overview of the program, the analytical development of the equations, and several tutorial appendices.
Volume III contains a user's guide and module descriptions.
Volume IV contains the actual program listings.
The Addendum contains sample run input and output data.

1.4 Approach

The following ground rules proscribe the approach to program modification and documentation:

1. The program structure and control was to be changed not at all.
2. The program code was to be changed as little as possible consistent with achieving the stated objectives.
3. The program documentation was to be completely re-organized and expanded to be full and accurate. (This has resulted in completely new documentation.)
4. Program checkout was to be accomplished using the internal (interim) trajectory module -- with subsequent use of a trajectory module, interfacing with a refined version of PROFGEN, intended as the "operational" mode.

2.0 Summary and Conclusions

2.1 Summary

THe structure and control of the INSS program has been preserved so that existing CDC "setup" programs may continue to be used. However, the output formats were necessarily changed to accommodate attitude and attitude errors. This modular program structure is illustrated in the functional block diagram, Figure 1-1.

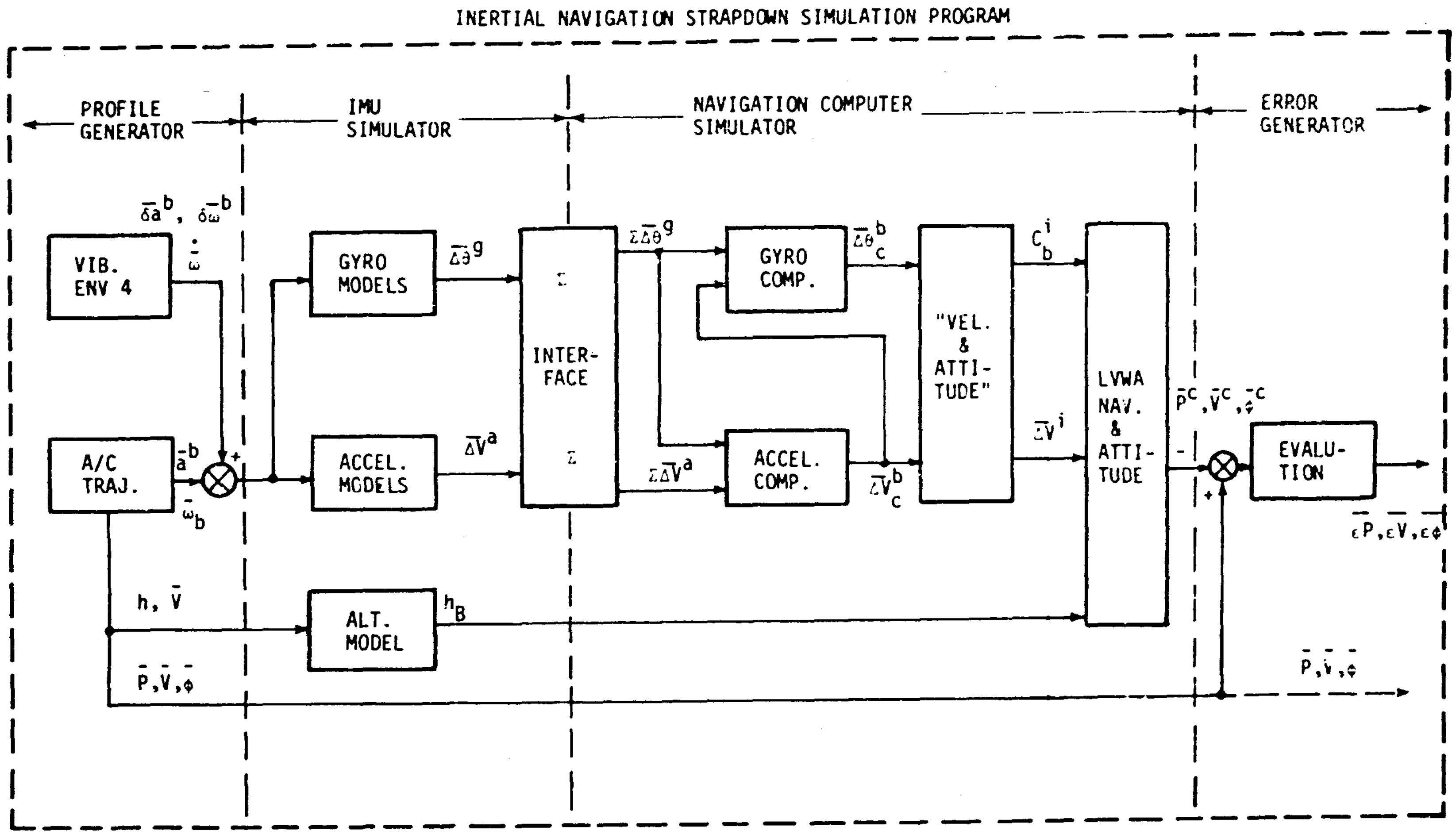

Figure 1-1. INSS Functional Block Diagram

Since the modules themselves were drawn from different sources, using different implied definitions of fundamental coordinate frames, it was necessary to return to the module listings to reconstruct the intended frames and the intervening transformations. When this task was completed and documented, attitude was added with minimal changes to the modules.

The earlier rewrites and expansions of the program description had resulted in documentation that diverged in some cases, from the program listings. This, too, required the analyst to deduce the equations actually mechanized from the program listings, and then rederive said equations, often from first principles, and compare the resulting algorithms with those obtained by "inverse Fortran transforming" the program listings. Where discrepancies were noted, the new derivations were rechecked, and any surviving errors were corrected. Most of the errors noted were either sign errors or multiply-or-divide by Δt errors. Minor deficiencies, such as phasing errors in the navigation algorithm, were removed during the software upgrading.

The only major program changes were the creation of two modules to replace the originally-supplied laser gyro module and its opposite number, the laser gyro compensation module.

Program changes were checked out by performing short test runs on an as-needed basis -- using the interim trajectory module. With the upgraded navigation software, some apparent errors will be introduced by the interim trajectory module itself so the ultimate test must be performed with the latest version of PROFGEN.

Completely new, full documentation has been generated to describe the "new baseline" INSS program, with the remaining deficiencies duly noted.

Use of the program with anything other than the default values will entail a considerable amount of preparation due to the sheer number and form of the input parameters available. As an example, to describe the inertial component alignments, misalignments and non-orthogonalities, the user may be required to precompute and insert 117 parameters into 4 modules.

2.2 Conclusions and Recommendations

1. The INSS is ready for extensive evaluation with the refined PROFGEN program and its related trajectory module. (These latter have been developed by AFAL, but, to date, user documentation has not been published.)

2. Initial performance checks could reasonably compare INSS errors (with no intended compensation errors) with the full-up NUMSIM (5) errors (the latter assumes ideal sensors) when both are driven from the same PROFGEN trajectory tape.

3. For ease of comparison of errors it may be considered expedient to add the computation of long and short term rms errors to the INSS evaluation module as is done in NUMSIM.

4. Building up a set of intertial component models and compensation errors will require some study of manufacturer's design and test data, together with perusal of the appropriate sections of Volume III to find what parameters are required -- and of Volume II -- to find how to derive or deduce them from available data.

5. The INSS provides considerable freedom in the orientation of the inertial components within inertial measuring unit. Manufacturer's data should provide the nominal orientations and anticipated alignment accuracies. Test results provide actual orientations and stability of same.

6. Component errors are the differences between the true parameters -- inserted in the component model -- and the "loaded" or calibration values -- inserted in the compensation module. Random errors are, of course, not compensated.

7. Fundamental parameters for the inertial components, such as loop elastic restraint, pendulosity, angular momentum and the like must have finite nonzero values. This is also true of quantization in the accelerometer and SDF gyro modules.

8. Secondary parameters such as scale factor nonlinearities, gyro torque coefficients, and the like may have zero values.

9. Default values -- in the initialization data files -- may be considered typical of a moderate accuracy INS -- but individual parameters, for comparable performance, may vary by an order of magnitude from the default values.

10. As presently configured, the effects of the random vibration environment -- linear and angular acceleration and angular velocity -- are "felt" only by the simulated inertial components but are not super-imposed on the reference profile. Thus, the simulated INS is charged with position, velocity, and attitude "errors" for which

it is not responsible. It would, therefore, be expedient to modify the PROFGEN-INSS so the random vibration from ENV is incorporated into the PROFGEN output at the position, velocity, and attitude levels as well as at the acceleration and angular velocity levels.*

11. The above modification is a necessary precursor to the evaluation of the accuracy of any alignment scheme, via Kalman filter or otherwise, since the object of the scheme is to limit the instantaneous values of the initial condition errors of the INS when the last update is applied.**

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* This activity was started under the present contract but subsequently terminated.

** A Kalman filter for ground-based alignment of a strapdown INS was developed, tested, and partially integrated with the INSS modules under the present program. Listings, rough rates and sample runs were supplied to AFAL.

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